

# STRUCTURAL DESIGN II

## 04. DESIGN OF TENSION MEMBERS

**KIRAN S. R.**

Lecturer



Department of Civil Engineering

**Central Polytechnic College Thiruvananthapuram**

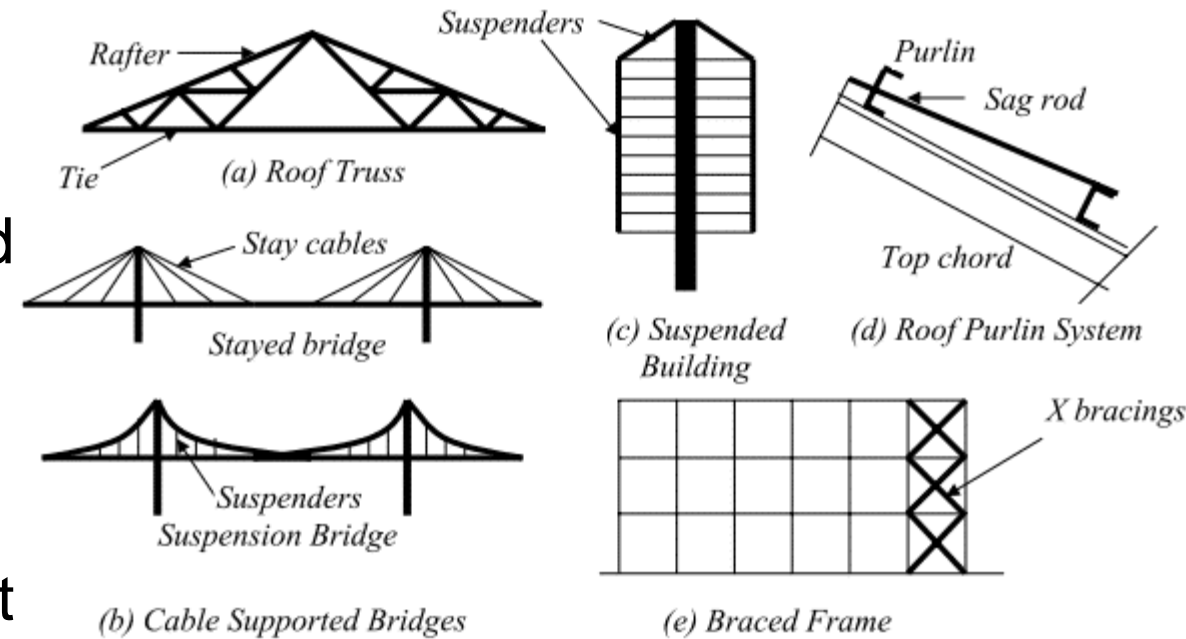
# INTRODUCTION

- Tension members are those subjected to direct axial tensile force.

## SLENDERNESS RATIO:

- Although, tension members do not buckle locally or overall, IS800 stipulates maximum slenderness ratio for tension members, in order to ensure a minimum **stiffness** to prevent undesirable lateral movement & excessive vibrations.

$$\text{Slenderness Ratio} = \frac{\text{Unsupported Length}}{\text{Least Radius of Gyration}}$$



Member	Maximum effective slenderness ratio ( $L/r$ )
A tension member in which a reversal of direct stress occurs due to loads other than wind or seismic forces	180
A member subjected to compressive forces resulting only from a combination of wind/earthquake actions, provided the deformation of such a member does not adversely affect the stresses in any part of the structure	250
A member normally acting as a tie in a roof truss or a bracing member, which is not considered effective when subject to reversal of stress resulting from the action of wind or earthquake forces	350
Members always in tension (other than pre-tensioned members)	400

**Table 3**  
**Page 20**  
**of IS800**

# MODES OF FAILURE

- 1) Gross Section Yielding
- 2) Net Section Rupture
- 3) Block Shear failure

# 1) GROSS SECTION YIELDING

- Although, a tension member without bolt holes can resist loads up to the ultimate load, it becomes unserviceable by undergoing large deformation (yielding).
- Hence, **yield strength of material ( $f_y$ )** is the deciding parameter here. Design strength is given by: (Page 32 - Cl.6.2 of IS800)

## 6.2 Design Strength Due to Yielding of Gross Section

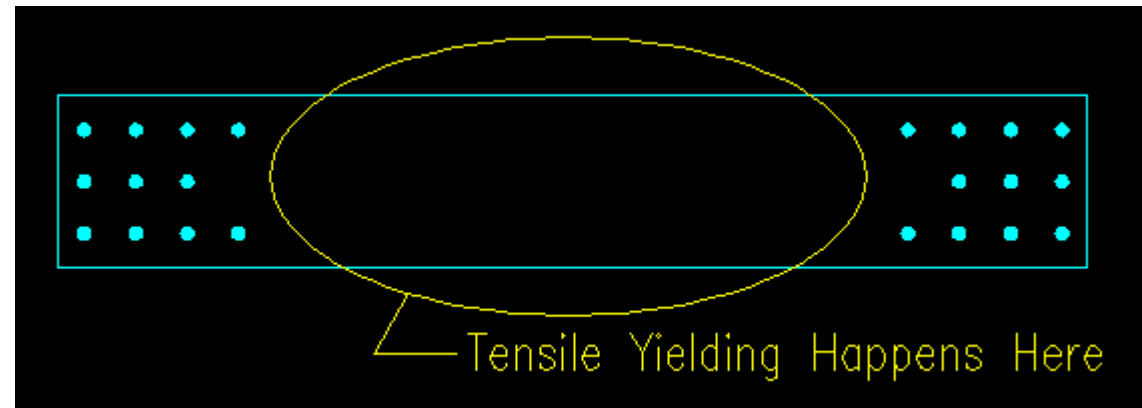
The design strength of members under axial tension,  $T_{dg}$ , as governed by yielding of gross section, is given by

$$T_{dg} = A_g f_y / \gamma_{m0}$$

$f_y$  = yield stress of the material,

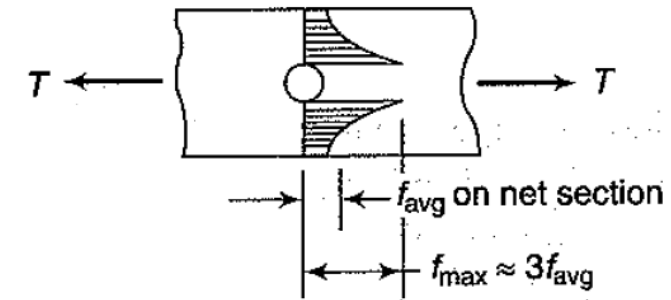
$A_g$  = gross area of cross-section, and

$\gamma_{m0}$  = partial safety factor for failure in tension by yielding = 1.10



## 2) NET SECTION RUPTURE

- Holes in the members cause stress concentration at service loads, as shown.
- Since stress adjacent to the hole is much higher than that at the periphery, rupture initiates in the material adjacent to the hole after the peripheral fibre had reached yield stress.
- Hence, **ultimate strength of the material ( $f_u$ )** is the deciding parameter here.



Design strength of plates due to net section rupture is given by: (Page 32 - Cl. 6.3 of IS800)

### 6.3 Design Strength Due to Rupture of Critical Section

#### 6.3.1 Plates

The design strength in tension of a plate,  $T_{dn}$ , as governed by rupture of net cross-sectional area,  $A_n$ , at the holes is given by

$$T_{dn} = 0.9 A_n f_u / \gamma_{m1}$$

where

$\gamma_{m1}$  = partial safety factor for failure at ultimate stress = 1.25

$f_u$  = ultimate stress of the material, and

$A_n$  = net effective area of the member given by,

$$A_n = (b - nd_h)t \quad (\text{for non-staggered holes})$$

$$A_n = \left[ b - nd_h + \sum_{i=1}^m \frac{p_{si}^2}{4g_i} \right] t$$

(for staggered holes)

$b, t$  = width and thickness of the plate

$d_h$  = diameter of the bolt hole

$g$  = gauge length between the bolt holes

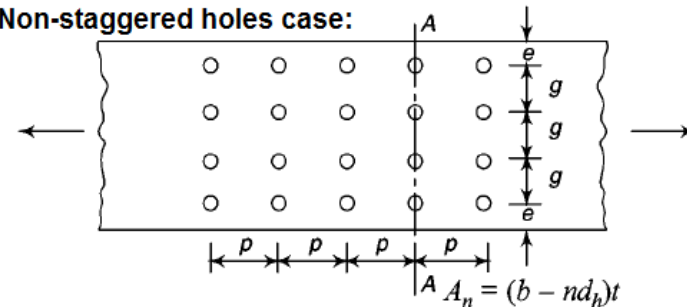
$p_s$  = staggered pitch length

$n$  = number of bolt holes in the critical section

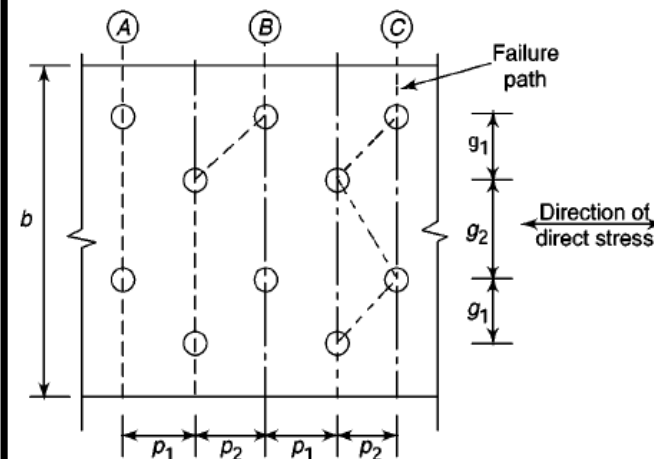
$i$  = subscript for summation of all the inclined legs.

#### EXAMPLES OF COMPUTING NET AREA

(a) Non-staggered holes case:



(b) Staggered holes case



On line A:

$$A_n = t[b - 2d_h]$$

On line B:

$$A_n = t[b - 3d_h + 0.25 p_2^2 / g_1]$$

On line C:

$$A_n = t[b - 4d_h + 0.5 p_2^2 / g_1 + 0.25 p_2^2 / g_2]$$

Failure paths may occur along sections normal to the axis of member and/or may include zigzag sections also, if bolts are staggered.

All possible failure paths must be considered and corresponding net areas to be computed to determine the minimum area of the plate.

### 6.3.3 Single Angles

The rupture strength of an angle connected through one leg is affected by shear lag. The design strength,  $T_{dn}$ , as governed by rupture at net section is given by:

$$T_{dn} = 0.9 A_{nc} f_u / \gamma_{m1} + \beta A_{go} f_y / \gamma_{m0}$$

(for connected leg) (for outstanding leg)

where

$$\beta = 1.4 - 0.076 (w/t) (f_y/f_u) (b_s/L_c) \leq (f_u \gamma_{m0} / f_y \gamma_{m1}) \geq 0.7$$

$w$  = outstand leg width,

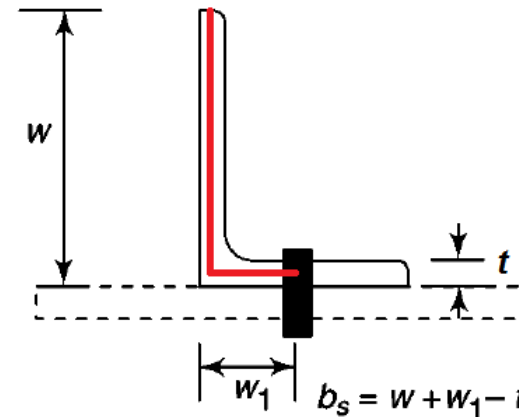
$L_c$  = length of the end connection, that is the distance between the outermost bolts in the end joint measured along the load direction or length of the weld along the load direction.

$A_n$  = net area of the total cross-section

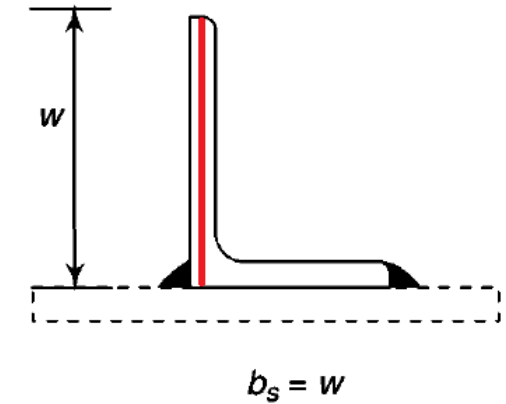
$A_{nc}$  = net area of the connected leg

$A_{go}$  = gross area of the outstanding leg

$t$  = thickness of the leg



(a) Bolted connection

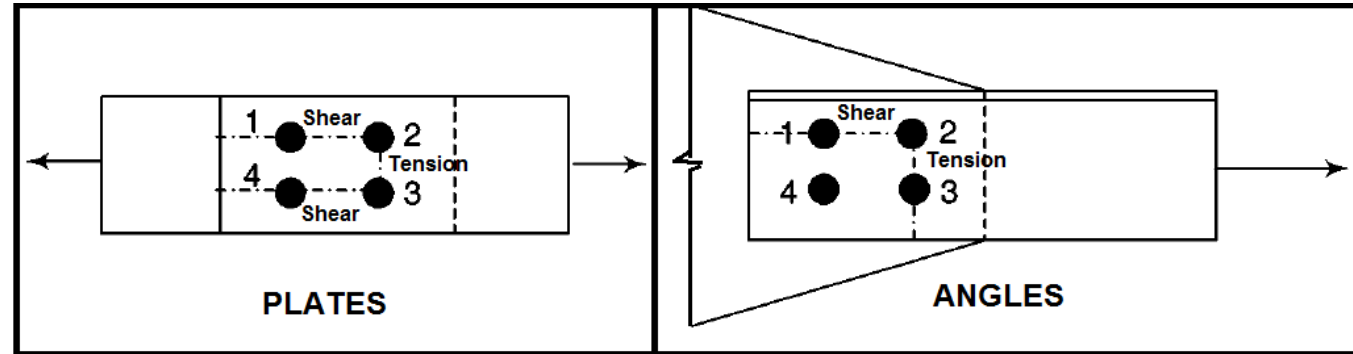


(b) Welded connection

Here,  $b_s$  is the **shear lag width**, i.e., the shear distance from the edge of the outstanding leg to the nearest line of fasteners, measured along the centre line of the legs in the cross section.

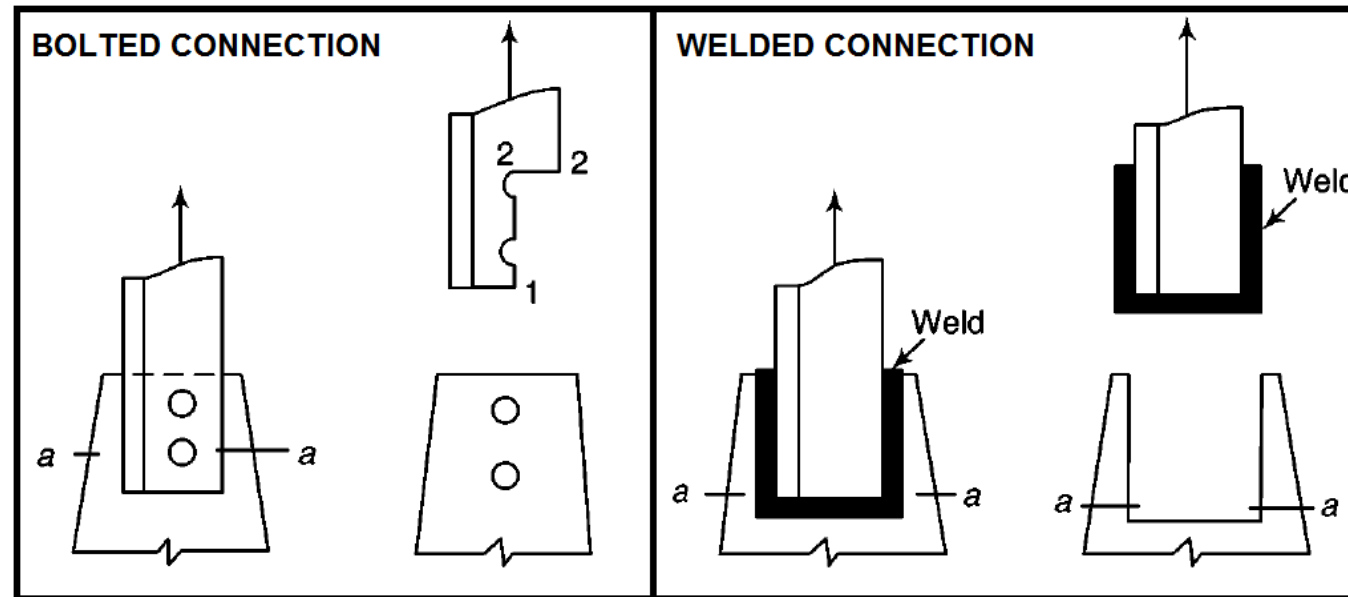
### 3) BLOCK SHEAR FAILURE

- Failure of the member occurs along a path involving tension on one plane and shear on a perpendicular plane along the fasteners as shown.



- Block shear Failure occurs under the following circumstances:
  - When the bearing strength of plate as well as the shear strength of bolt are higher, only fewer bolts are required in connection. Thus, smaller connection length may result in Block shear failure.
  - It may also occur when bolts are closely spaced.

- Failure possibilities for different connections is shown below



# NUMERICAL EXAMPLE 1

Compute tensile strength of an angle 150 x 115 x 8 mm of Fe410 grade connected to gusset plate by weld over 140mm length.

---

Answer:

Tensile strength of a steel section = Min. of  $\left\{ \begin{array}{l} 1) \text{ Design strength due to gross section yielding} \\ 2) \text{ Design strength due to net section rupture} \end{array} \right.$

**1) Design strength due to gross section yielding,  $T_{dg} = \frac{f_y A_g}{\gamma_{mo}}$**  (Page32 – Cl.6.2 of IS800)

$f_y = 250 \text{ N/mm}^2$  (Min. yield strength for Fe410 grade steel of <20mm thickness = 250N/mm<sup>2</sup>)

$A_g = 2058 \text{ mm}^2$  (for ISA150x115x8 from steel tables)

$\gamma_{mo} = 1.10$

Design strength due to gross section yielding,  $T_{dg} = \frac{250 \times 2058}{1.10} = \mathbf{467.73 \text{ kN}}$

# NUMERICAL EXAMPLE 1

Compute tensile strength of an angle 150 x 115 x 8 mm of Fe410 grade connected to gusset plate by weld over 140mm length.

2) Design strength due to net section rupture,  $T_{dn} = \frac{0.9A_{nc}f_u}{\gamma_{m1}} + \frac{\beta A_{go}f_y}{\gamma_{mo}}$  (Page33 – Cl.6.3.3 of IS800)

$$A_{nc} = (150 - 8/2) \times 8 = 1168 \text{ mm}^2$$

$$A_{go} = (115 - 8/2) \times 8 = 888 \text{ mm}^2$$

$$f_u = 410 \text{ N/mm}^2$$

$$f_y = 250 \text{ N/mm}^2 \text{ (for Fe410 grade steel)}$$

$$\gamma_{m1} = 1.25$$

$$\gamma_{mo} = 1.10$$

$$\beta = 1.4 - 0.076 \frac{w}{t} \frac{f_y}{f_u} \frac{b_s}{L_c} = 0.85$$

$$\text{Min } \beta = 0.70$$

$$\text{Max } \beta = \frac{f_u \gamma_{mo}}{f_y \gamma_{m1}} = \frac{410 \times 1.10}{250 \times 1.25} = 1.44$$

0.85

$$w = 115 \text{ mm}$$

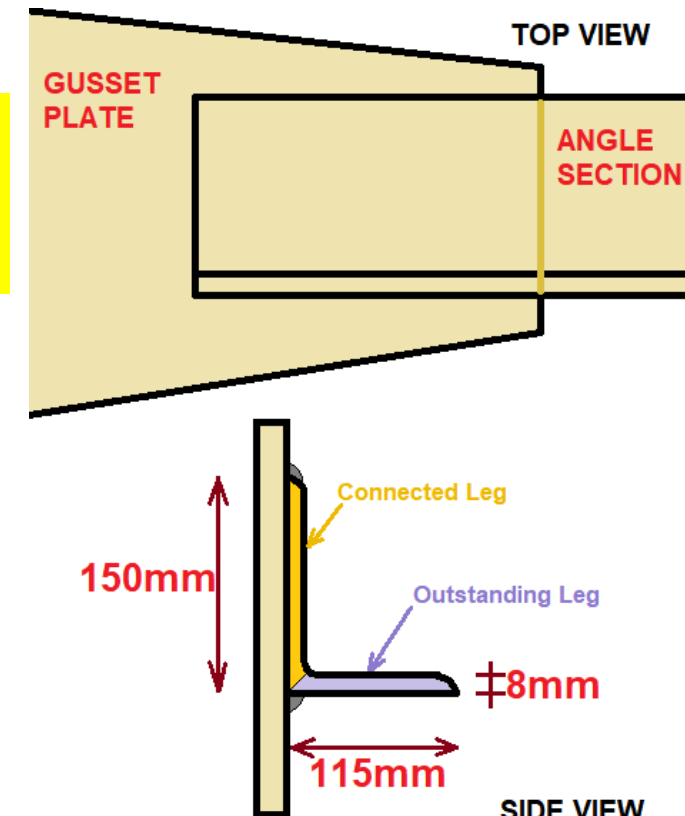
$$t = 8 \text{ mm}$$

$$b_s = w = 115 \text{ mm}$$

$$L_c = 140 \text{ mm}$$

Generally, wider leg of angle is connected to the gusset plate.

$$\begin{aligned} \text{Design strength due to net section rupture, } T_{dn} &= \frac{0.9 \times 1168 \times 410}{1.25} + \frac{0.85 \times 888 \times 250}{1.10} \\ &= 516.34 \text{ kN} \end{aligned}$$



# NUMERICAL EXAMPLE 1

**Compute tensile strength of an angle 150 x 115 x 8 mm of Fe410 grade connected to gusset plate by weld over 140mm length.**

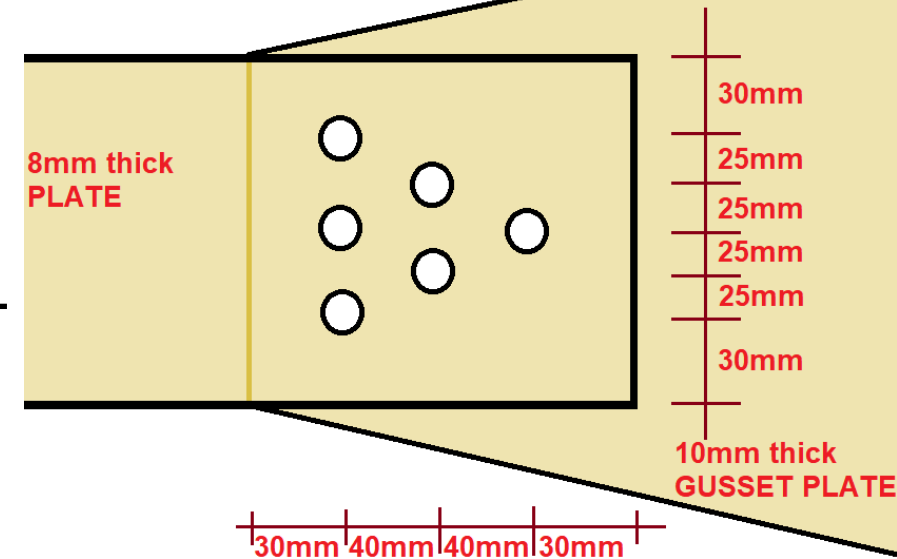
---

Tensile strength of the given angle section

$$\begin{aligned} &= \text{Min. of} \left\{ \begin{array}{ll} 1) \text{ Design strength due to gross section yielding} & = 467.73 \text{ kN} \\ 2) \text{ Design strength due to net section rupture} & = 516.34 \text{ kN} \end{array} \right. \\ &= 467.73 \text{ kN} \end{aligned}$$

# NUMERICAL EXAMPLE 2

Determine the design tensile strength of a plate 160 x 8 mm of Fe410 grade connected to gusset plate of 10mm thick using M16 bolts as shown.



Answer:

Tensile strength of a steel section = Min. of

- 1) Design strength due to gross section yielding
- 2) Design strength due to net section rupture

**1) Design strength due to gross section yielding,  $T_{dg} = \frac{f_y A_g}{\gamma_{mo}}$**  (Page 32 – Cl. 6.2 of IS 800)

$f_y = 250 \text{ N/mm}^2$  (Min. yield strength for Fe410 grade steel of <20mm thickness = 250 N/mm<sup>2</sup>)

$A_g = 160 \times 8 = 1280 \text{ mm}^2$  (for 8mm thick plate, width = (30+25+25+25+25+30)=160mm)

$\gamma_{mo} = 1.10$

Design strength due to gross section yielding,  $T_{dg} = \frac{250 \times 1280}{1.10} = \mathbf{290.91 \text{ kN}}$

# NUMERICAL EXAMPLE 2

Determine the design tensile strength of a plate 160 x 8 mm of Fe410 grade connected to gusset plate of 10mm thick using M16 bolts as shown.

2) Design strength due to net section rupture,  $T_{dn} = \frac{0.9A_n f_u}{\gamma_{m1}}$  (Page33 – Cl.6.3.3)

$$A_n = (b - nd_h + \sum \frac{p^2}{4g})t$$

$$b=160\text{mm}$$

$$d_h = 16+2=18\text{mm}$$

$$p=40\text{mm}$$

$$g=25\text{mm}$$

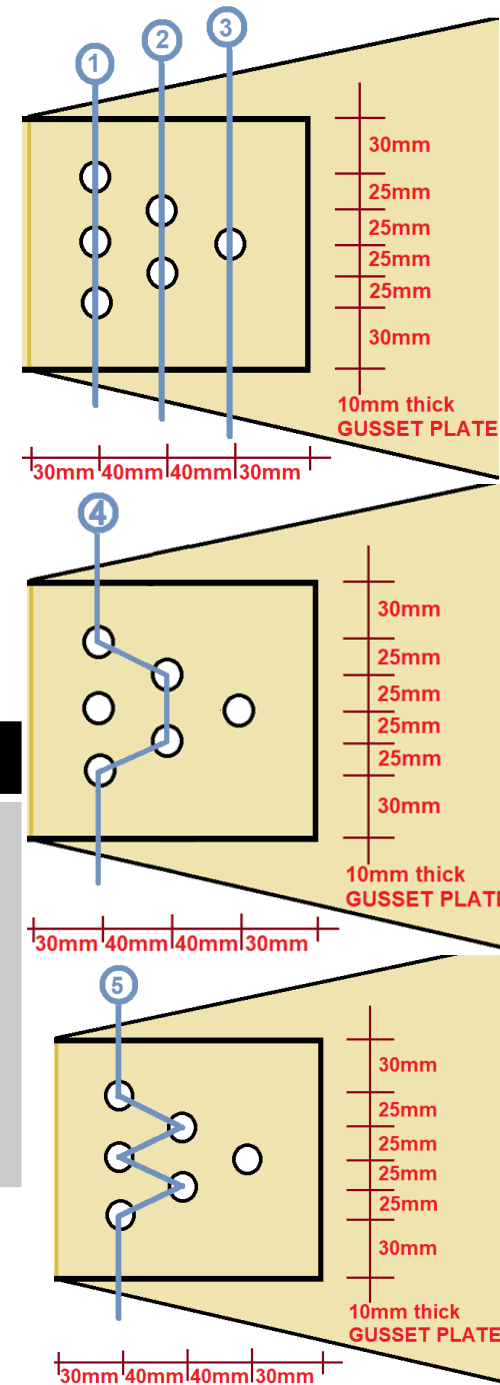
All possible failure paths are considered as shown in figure and corresponding net areas to be computed to determine the minimum net area of the plate.

Failure path	Corresponding Net Area (in mm <sup>2</sup> )	Min. Net Area
1	$(160 - 3 \times 18 + 0) \times 8 = 848$	<b>848 mm<sup>2</sup></b>
2	$(160 - 2 \times 18 + 0) \times 8 = 992$	
3	$(160 - 1 \times 18 + 0) \times 8 = 1136$	
4	$(160 - 4 \times 18 + (\frac{40^2}{4 \times 25}) + (\frac{40^2}{4 \times 25})) \times 8 = 960$	
5	$(160 - 5 \times 18 + (\frac{40^2}{4 \times 25}) + (\frac{40^2}{4 \times 25}) + (\frac{40^2}{4 \times 25}) + (\frac{40^2}{4 \times 25})) \times 8 = 1072$	

$$f_u = 410\text{N/mm}^2$$

$$\gamma_{m1} = 1.25$$

$$\text{Design strength due to net section rupture, } T_{dn} = \frac{0.9 \times 848 \times 410}{1.25} = 250.33 \text{ kN}$$



# NUMERICAL EXAMPLE 2

**Determine the design tensile strength of a plate 160 x 8 mm of Fe410 grade connected to gusset plate of 10mm thick using M16 bolts as shown.**

---

Design Tensile strength of the given plate

$$\begin{aligned} &= \text{Min. of} \left\{ \begin{array}{ll} 1) \text{ Design strength due to gross section yielding} & = 290.91 \text{ kN} \\ 2) \text{ Design strength due to net section rupture} & = 250.33 \text{ kN} \end{array} \right. \\ &= \mathbf{250.33 \text{ kN}} \end{aligned}$$

# THANK YOU